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A comparison of diversity and composition of carabid beetles between overpasses and underpasses in fragmented forest areas

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ABSTRACT

Wildlife crossing structures are important for increasing biodiversity of wildlife and other animals. Thus, the objective of this study was to compare the community structure of carabid beetles along environmental transects of forest–edge–crossing structures in fragmented forest areas. In addition, we also investigated whether there were differences in carabid beetle assemblages due to structural differences in crossing structures, i.e., overpass and underpass. A total of 3,737 carabid beetles belonging to 60 species were collected by pitfall trapping across environmental transects from June 6 to September 3, 2015. In crossing structures, environmental variables, such as soil texture, soil organic matters, and habitat structures were different from those in neighboring habitats. Abundance and species richness of carabid beetles in underpasses were significantly lower than those in neighboring habitats and overpasses. In particular, underpasses, especially those with more artificial structures in terms of soil properties and microhabitat, appeared to be less appropriate structures for movement of carabid beetles. Although less carabid beetle species were caught in crossing structures, species composition of carabid beetles were more similar to forest areas. In conclusion, efforts are needed to improve the connectivity of habitats and consider the needs of invertebrates by providing suitable microhabitats for wildlife crossing structures.

Introduction

Wildlife crossing structures as habitat corridors in fragmented landscapes have important roles in biodiversity conservation. They allow for the dispersal of animals (Haddad et al., 2003; White, 2007). In fragmented landscapes, road constructions can affect the biota directly (e.g., road-kills and biodiversity loss) and indirectly (e.g., changes of microclimate) (Coffin, 2007). To minimize the negative effect of habitat fragmentations, several types of wildlife crossing structures have been constructed. Wildlife crossings are generally designed to harmonize with their surrounding environments, and they can increase the biodiversity of vertebrates (Bond and Jones, 2008; Georgii et al., 2011) and invertebrates (Corlatti et al., 2009; Georgii et al., 2011; Jung et al., 2016). In a broad sense, wildlife crossing types are divided into overpasses and underpasses (White, 2007). In underpasses, animals can pass under an intersecting roadway through viaducts or culverts, while bridges with vegetation are the general types of overpasses for animals. Unlike overpasses, vegetation is not generally found in culvert type underpasses.

In recent, although there are many empirical studies to explore the effect of habitat fragmentation (e.g., Haddad et al., 2003; Orrock et al., 2011; Resasco et al., 2014) on animals, especially for insects, few studies has been conducted for examining effect of crossing structures types on animals (Bond and Jones, 2008; Georgii et al., 2011). In particular, Georgii et al. (2011) examined that butterflies, carabid beetles, grasshoppers, and spiders can effectively use an overpass when species-specific habitat elements are present on the overpass. On the contrary, Bond and Jones (2008) compared movement rate of vertebrates between overpasses and underpasses, and demonstrated that both structure types were used by various wildlife taxa. However, dispersal patterns of insects to the variation of environmental characteristics depending wildlife crossing structures remains unclear, because environmental characteristics in crossing structures possibly correlate to insect movements (e.g., Jung et al., 2016).

In Korea, number of wildlife crossing structures has been dramatically increased from 159 in 2005 to 415 in 2014 (NIE, 2015). However,

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there are still argued in ecological functions and management of wildlife crossing structures after construction. In particular, critical difference in vegetation structure and brightness between overpass and underpass (i.e., culvert type underpass for large mammals in our study) might affect movements of carabid beetles, because they have low dispersal ability than other insects that are capable of flying. In fact, many carabid beetle species are active fliers, but forest specialist carabid beetles are known to crawl on ground surface because they have shorter or fully reduced hind wings in general. In addition, carabid beetles have sensitive response to rapid environmental changes caused by anthropogenic disturbances (Lövei and Sunderland, 1996) and they can be collected with pitfall traps as standard sampling method (Rainio and Niemelä, 2003). For example, movement rates of carabid beetle species negatively influenced by highway (Koivula and Vermeulen, 2005) and narrow roads (Yamada et al., 2010).

Therefore, the objective of this study was to compare the community structure of carabid beetles along transects of forest–edge–crossing structures in fragmented forest areas. In addition, we also investigated whether there were differences in carabid beetle assemblages considering ecological functional traits (habitat types and wing dimorphisms) due to structural differences according to crossing structure types (i.e., overpass and underpass), because there is no evidence about the response of insects to wildlife crossing structure types. These works would be helpful for enhancing the role of wildlife crossings in biodiversity conservation.

Materials and methods

Study area

To study carabid beetle assemblages in crossing structures and neighboring habitats, eight study sites were selected based on crossing structure types constructed along several mountain ranges (Table 1), and their representative photographs were given (Fig. 1). Latitude and longitude of study sites were 36° 39′ 03.0″–37° 45′ 19.1″ and 127° 52′ 52.5″–128° 51′ 10.3″, respectively. Length and width in overpasses were 15.0–40.2 m and 4.5–12.0 m, respectively, while those in underpasses were 20.0–78.6 m and 2.5–15.0 m, respectively (Fig. 2). Among four overpasses, two overpasses in Gangneung-si (OGa and OGb) were more similar to each other in terms of crossing structure shape (Fig. 1a) and altitude. An overpass in Danyang (OD) was the largest crossing structure in terms of crossing structure length and width, and thus many plant species were found in the crossing structure (Fig. 1b). An overpass in Munkyeoung (OM) was the smallest, and vegetation was rather simple than other overpasses (i.e., no shrubs and herbs were found in the crossing structure). Among underpasses, three underpasses (UGa, UGb, and US) were rather similar to each other in terms of crossing structure shape (Fig. 1a), although US was the widest and shortest underpass. In underpasses, a set of stumps and root wads, that shelter for some small animals during crossing the way, were usually found. In addition, footprint tracking plates with fine sands were intendedly placed in the entrances of culverts of UGa and UGb to monitor wildlife movement. Unlike other underpasses, an underpass in Hongcheon was rather different in terms of neighboring habitat (i.e., southern forest far away from the wildlife crossing entrance about 100 m) and drainage channel (i.e. channels constructed in front of wildlife crossing entrances) (Figs. 1d, 2b). Therefore, wildlife crossing structures in our study were varied in terms of structures shapes (length and width), location, and vegetation. Nonetheless, we were forced to conduct studies on only 4 overpasses and 4 underpasses due to the lack of available crossing structures located in well preserved forest landscapes.

Sampling

To understand soil properties and environmental characteristics of our study sites, soil textures and organic matters were measured by using three soil samples from crossing structures (i.e., overpass and underpass) and both side of forest interiors, and all measurements were performed at the NICEM (Seoul National University, Seoul, Korea). Additional soil samples were collected within a radius of 1 m around each trap and subjected to measurement of soil moisture and soil pH in the laboratory. In addition, the percentages of herb coverage and canopy closure were estimated within a radius of 1 m around each trap. In culverts, the cover of canopy closure and herbal layer were measured by 100% and 0%, respectively, because no vegetation was found in culverts. From July 3 to September 3, the temperature and relative humidity in northern (western) forest, crossing structure, and southern (eastern) forest were measured using HOBO data loggers (Onset, U23 Pro v2 with solar radiation shields in crossing structures and U12-013 with shield cases in forests). Thus, a total of 24 HOBO data loggers was installed.

To collect carabid beetles, pitfall traps were used. Pitfall trapping is a standard sampling method for comparing the abundance or community structure of carabid beetles (Niemelä, 1996; Koivula et al., 2003). Pitfall traps were constructed using two plastic cups (inner cup, 430 ml in volume, 75 mm in diameter, and 100 mm in depth; outer cup, 500 ml in volume, 75 mm in diameter, and 120 mm in depth) and placed flush with soil surface. The inner cup was half-filled with preservatives (95% ethyl-alcohol:95% ethylene-glycol = 1:1) as killing-preserving solution. Because much wildlife might use the crossing structures, a square-type wire net (25 cm^2 with 2.5 cm^2 mesh) was placed on the top of each trap to prevent disturbance by animals. In addition, a plastic roof (20 cm^2) was placed at 3 cm above each trap to prevent the inflow of

Table 1
Site description of 4 overpasses and 4 underpasses.

Site code	Location[a]	Latitude/longitude	Altitude (m)	Road type	Crossing structure[b]			
					Construction year	Length (m)	Width (m)	Area (m^2)
Overpasses								
OGa	Gangneung-si, GW	N37° 37′ 12.7″/E128° 46′ 21.7″	688	Two-lane local road	2005	20.0	12.0	240.0
OGb	Gangneung-si, GW	N37° 34′ 37.0″/E128° 51′ 10.3″	689	Two-lane local road	2003	32.0	11.0	352.0
OD	Danyang-gun, CB	N36° 48′ 31.5″/E128° 21′ 18.2″	865	Two-lane local road	2009	40.2	10.0	402.0
OM	Mungyeong-si, GB	N36° 39′ 01.9″/E128° 02′ 12.3″	223	Two-lane local road	2001	15.0	4.5	67.5
Underpasses								
UH	Hongcheon-gun, GW	N37° 45′ 29.0″/E127° 52′ 46.2″	219	Four-lane highway	2009	78.6	2.5	196.5
UGa	Gangneung-si, GW	N37° 43′ 55.8″/E128° 46′ 52.5″	423	Four-lane highway	2001	60.0	5.0	300.0
UGb	Gangneung-si, GW	N37° 44′ 41.8″/E128° 47′ 22.0″	331	Four-lane highway	2001	56.6	5.0	283.0
US	Samcheok-si, GW	N37° 23′ 01.3″/E129° 00′ 35.3″	803	Two-lane local road	2004	20.0	15.0	300.0

[a] Abbreviation of districts is: CB, Chungcheongbuk-do; GB, Gyeongsangbuk-do; GW, Gangwon-do.
[b] Length, width, and area of crossing structures were measured by crossing structure only without edge areas between crossing structure and forests.